Science Promise and Conceptual Mission Design for SAFIR - the Single Aperture Far Infrared Observatory

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"To take the next step in exploring this important part of the spectrum,the committee recommends the Single Aperture Far Infrared (SAFIR) Observatory, a passively cooled 8-meter class telescope that builds on the technology developed for NGST"

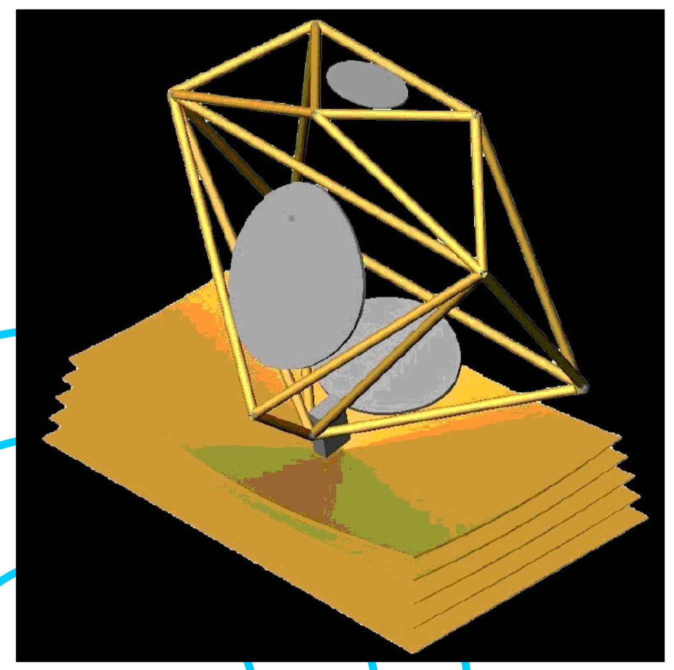
2000 NRC Decadal Report

SAFIR Mission Overview

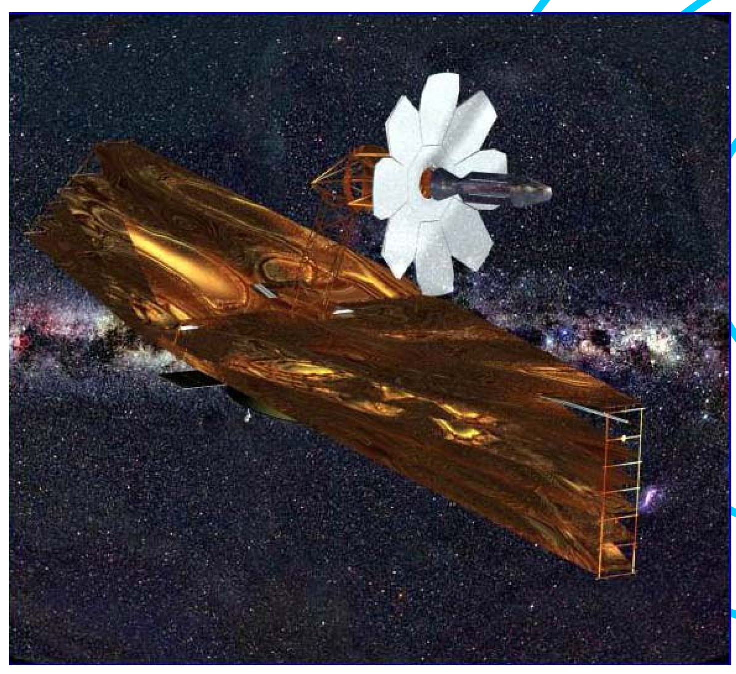
λ range (diffraction-limited)	30µm - 1mm
Deployed Aperture Size	8m-class, format TBD
Telescope Temperature	5-10K
Pointing	1" abs, 0.1" diff
Cooling	passive + cryocoolers
Orbit	Sun-Earth L2
Launch	~2015
Lifetime	> 5 years

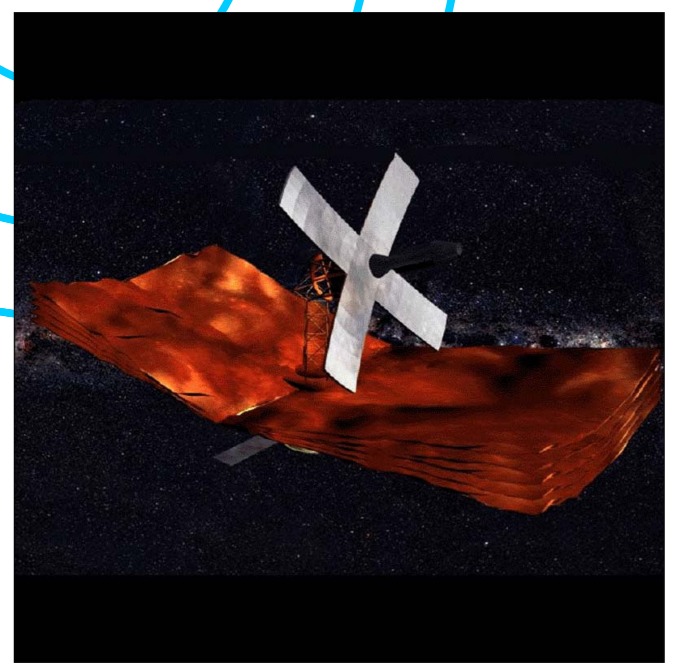
Instruments
- broadband camera
  - 10^4 pixel bolometer array, FOV ~4 arcminutes
- low resolution spectrometer
  - R~100; 20-100µm Ge:Ga?, >100µm bolometers?
- moderate resolution spectrometer
  - R~2000; photoconductor/bolometer arrays?
- high resolution spectrometer
  - R~10^6; 100-500µm; heterodyne mixers likely

Dual Anamorphic Reflector Telescope (DART) filled aperture concept with stretched membrane segments. Very high aperture/weight ratio.



Filled aperture concept with hex petal-deployed segments maximizes JWST heritage





Sparse slot-aperture JWST-like concept maximizes high spatial frequencies and offers simplified deployment.

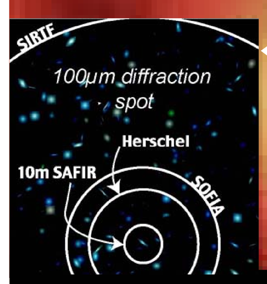
Different flavors of SAFIR … *but commonality in many technology needs!*

Spatial Resolution & SAFIR Science Promise

SAFIR will offer a huge improvement in the far IR

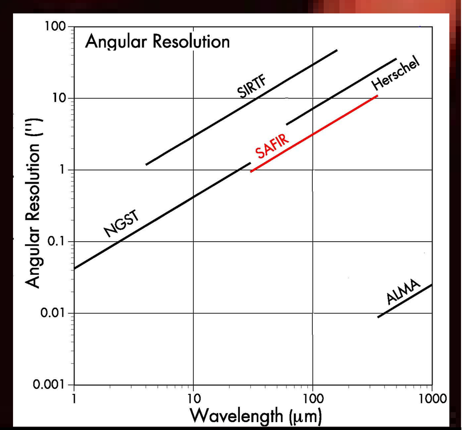
SAFIR will provide an order of magnitude higher spatial resolution than SIRTF, and will use this to distinguish high-z galaxies near their spectral peaks. It will resolve most of the high redshift background mapped by COBE and ISO into indvidual galaxies. This will allow population studies of the first dust shrouded galaxies and spectroscopic analysis of their constituents. With a pixel size of order that of the ALMA primary beam, and with its ability to see warmer dust from starburst and active galaxies, it will have important scientific complementarity to ALMA, heralding future space-based FIR interferometers.

background , SCUBA 850µm HDF

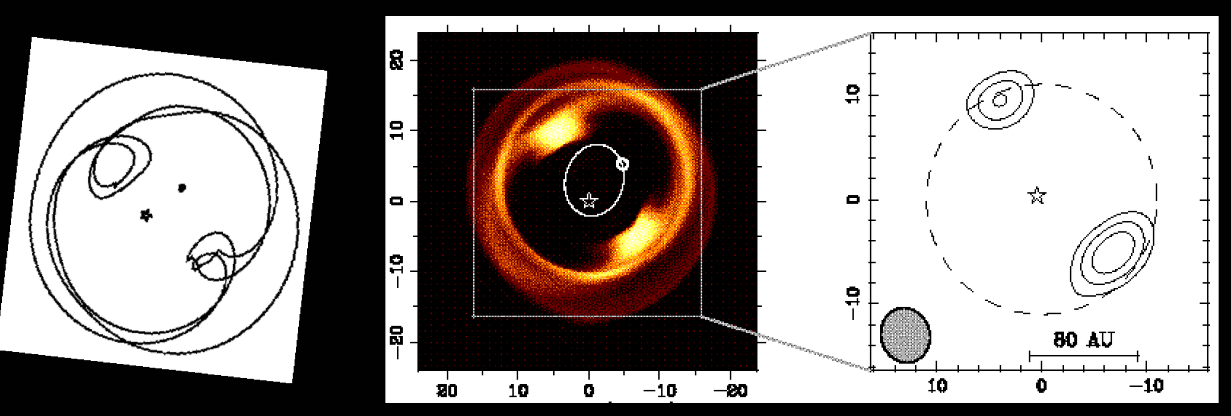


At left, far IR observatory spatial resolution overlaid on a simulation of the 100µm background.

all images here on the same scale!



At bottom, millimeter wave observations of the cold parts of the debris cloud around Vega (also on the same scale as above), a representative nearby debris cloud, and the interpretation of the peaks in terms of orbital resonances due to a massive planet that is clearing the cloud. SAFIR will probe inner, warmer parts of these debris clouds around young nearby stars to look for evidence of young solar systems.



Wilner, Holman, Kuchner & Ho 2002

IRAM Plateau de Bure 1.3 mm

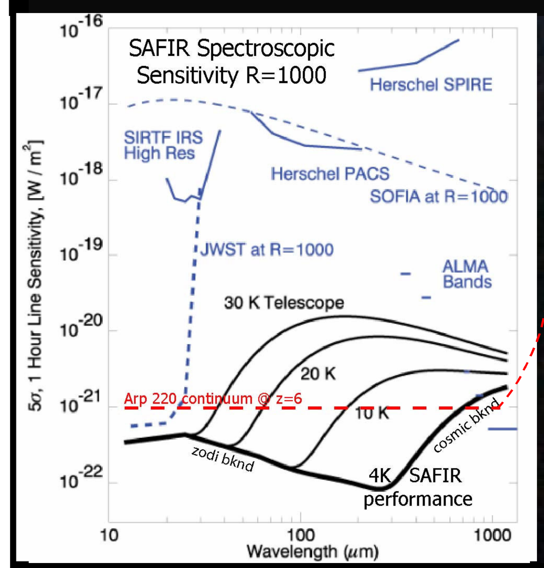
SAFIR offers far infrared astronomy a clarity that is unobtainable by any other existing or proposed single aperture telescope, and provides far IR data on scales that are well matched to modest ground based optical and near infrared capabilities.

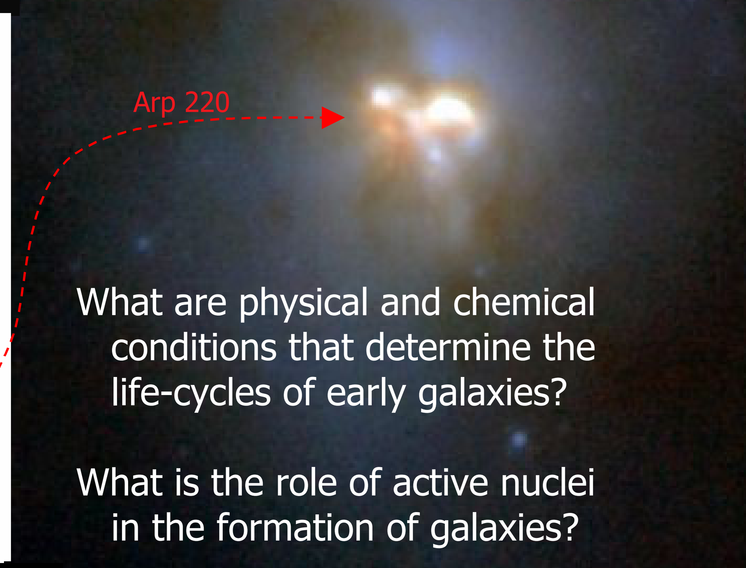
Sensitivity & SAFIR Science Promise

SAFIR will offer dramatic increases in IR sensitivity

With telescope temperatures approaching 4K, and collecting area more than a hundred times that of SIRTF, SAFIR will offer IR point source background limited sensitivities **orders of magnitude** better than other telescopes. SAFIR fills the "sensitivity gap" between JWST at short λ, and ALMA at long λ. It will, for example, let us see extinction-free infrared spectral & kinematic diagnostics from the earliest star forming galaxies.

Brα
PAHs
ArII
ArIII
SIV
NeII
NeIII
NeV
ArIV
SiII
SIII
OIV
FeII
FeIII
H2
OIII
NII
CII
CI
OI
OH
HD
SiI
H2O
CO
⋮

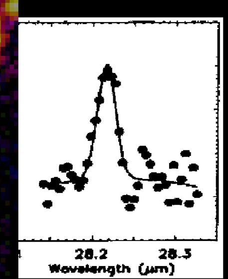




What are physical and chemical conditions that determine the life-cycles of early galaxies?

What is the role of active nuclei in the formation of galaxies?

With this high sensitivity , SAFIR will be confusion limited at low spectral resolutions. At high spectral resolution, however, SAFIR will be able to fully capitalize on the sky-background limit.

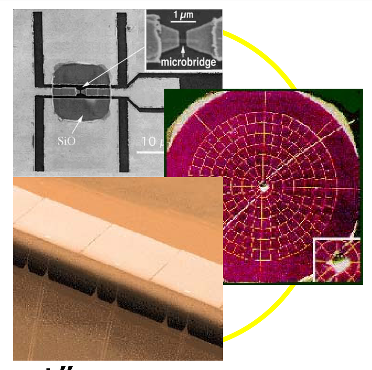


A stretch goal of SAFIR that will challenge observatory sensitivity will be the detection of the brightest quadrupole lines of primordial molecular hydrogen in the early universe after recombination, and during the first galaxy-building. With rest wavelength of 28µm, the 0-0 S(0) line will be redshifted into the far infrared and submillimeter, near the background trough at 100-400µm. This line is expected to be the predominant coolant for pre-reionization protogalactic clouds, with virial temperatures of ~1500K. While the predicted strengths for this line are dependent on the extent of photodissociation by the first stars, even by pre-reionization soft-UV, galaxy-mass clumps of H_2 with those temperatures predict line strengths of order 10^{-21}-10^{-22} W-m^{-2} – of order background limited performance for SAFIR. Validation of a detection would come from line pair detection with the similarly strong H_2 S(1) 1-0 line at rest wavelength 17µm.

Long Wavelength Sensor Technology & SAFIR Science Promise

detector development on critical path to mission definition

THE NEED: large, sensitive detector systems
- in hand: IBC, semiconducting and TES detectors, array readout & format scaling strategies, heterodyne arrays up to 2 THz
- the road ahead: develop integrated systems suborbital demos using SOFIA, balloons, etc. develop industry-scale vendor base



transition from "handicraft" ⟶ "industrial development"

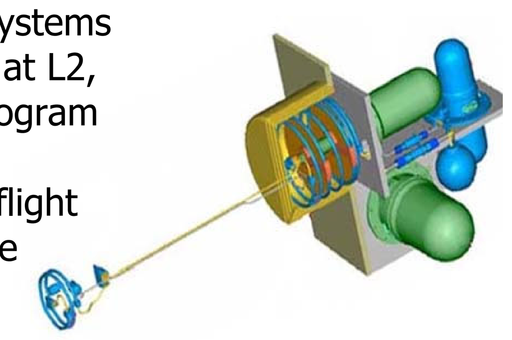
Primordial galaxy redshifts " luminosity functions	→	10^4 - element direct detection arrays (rich-field situation for far-IR & submm)
Local Star Formation Cloud & YSO kinematics	→	heterodyne arrays near quantum limit >3 THz

While efforts for SIRTF, SOFIA, and Herschel lead the way to satisfying our detector needs, present state-of-art is at least an order of magnitude away from where we need to be for background-limited spectroscopy, and about two orders of magnitude low in array format to fill usable focal plane.

Cooling Technology & SAFIR Science Promise

thermal control on critical path to mission definition

THE NEED: robust, powerful, efficient cooling systems
- in hand: proven expertise in passive cooling at L2, high efficiency cryocoolers from ACDTP program reaching <5K
- the road ahead: large deployable sunshields, flight qualification of high capacity coolers, active cooling of shields and support structure



use mission design heritage to achieve a large <10K telescope

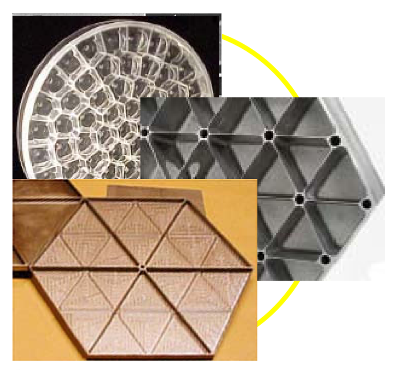
Primordial galaxies " H_2 before reionization	→	natural background-limited sensitivity probe background "hole" at 100-400µm

SAFIR observatory thermal control strategies follow naturally from recent successes with SIRTF and WMAP and benefit synergistically with development efforts for JWST and TPF. Focal plane cooling solutions come naturally from those missions, as well as from new high energy missions. SIRTF cooldown performance now validates many passive cooling models.

Cryogenic Optics Technology & SAFIR Science Promise

lightweight and cold substrates on critical path to mission definition

THE NEED: <10kg/m², affordable, ~1µm, ~4K
- in hand: lightweight, stiff, sub-meter sizes Be (4K demonstrated!), SiC, MgGr, Borosil AMSD, SBIR technology programs
- the road ahead: fab & test full-size (1-2m class) push cost to <$500K/m², fab rate >20 m²/yr engage industry for transition to mid-TRL



Such optics are critical to many NASA and DoD applications

Primordial galaxy redshifts " luminosity functions	→	<10K telescope, >10m effective diameter (rich-field situation for far-IR & submm)
Local Star Formation Cloud & YSO kinematics	→	surface accuracy and control bears on coherent efficiency and image quality

While JWST-style Be mirrors could be used for SAFIR, the areal density, production rate, and piecewise cost tend to discourage the large aperture spec that mission science requires. Factor of fifty relaxation of JWST surface figure requirement opens technological space for creative solutions.

More information at . . . http://safir.jpl.nasa.gov/

AAS #203 Atlanta January 2004 Lester et al. paper 22.19
Session 22 : First Results from the Space Infrared Telescope Facility (SIRTF)